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QUOTA AND RISK SHARING AMONG FISHERMEN.

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Quota and Risk Sharing among Fishermen

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Abstract. Pooling and exchange of random resources may o¤er the owners insurance and substitution. Greater e¢ciency and more stable revenues thereby obtain. These good properties derive from a sharing rule that complies with the core concept from cooperative production games. It is applied here to …sheries with stochastic yield.

Key words: Resource management, randomization, risk, insurance, cooperative games, core allocations, mutual exchange, stochastic programming, communal …sheries.

JEL classi…cation: C71, Q22.

1. Introduction

Most producers regard uncertain factor abundance as inconvenient. Such attitudes could stem from commonplace risk aversion. But often they hinge on - and are justi…ed by - the fact that some crucial factors are random and a¤ect payo¤s in nonlinear manners. Capacity limits have for instance, sometimes the concave e¤ect of curtailing pro…table production.

Fisheries are a case in point. Fluctuating stock sizes there oblige quota (and gear) owners to cope with troublesome ups and downs. Those owners may of course turn to insurance providers - or the government - and pay appropriate premium for agreed upon indemnities. Alternatively, the same …shermen might enter …nancial markets and hedge their bottom lines by means of various options. The merits of such instruments notwithstanding, it remains reasonable though, that the said …shermen also exploit own possibilities for mutual insurance to the full.

The prospects of doing so is precisely the object of this paper. Present several risk exposed quota holders, my aim is to demonstrate here how pooling and exchange of individual holdings opens for mutual insurance and substitution possibilities. What come up in this context are objects shared by stochastic programming, cooperative game theory, and insurance - in that order. To wit, …rst, coordinated optimization

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under uncertainty yields a stochastic vector of dual variables (contingent shadow prices) associated to shared random resources. Second, those prices generate a speci…c core solution of a so-called production game. And third, they equilibrate a market for quota and risk exchange.

Absence of sharing mechanisms (markets) often generates overcapitalized or subsidy-dependent …sheries, featuring overexploitation of commercially important …sh stocks. Partly to mitigate that dismal situation a preceding paper explored how core allocations may come about in …sheries plagued by no uncertainty [2]. The analysis is extended here to bring out the same sort of solutions for …sheries with stochastic yield. Essentially, such solutions allow cooperation across both time and contingencies. Important then is that individual payo¤ is determined by how own endowment co-varies with the aggregate.[1]

To set the stage Section 2 demonstrates this in a simpli…ed but not quite realistic setting. Uncertainty is there resolved in one shot, and agents prefer to wait and see. For greater realism Section 3 extends the analysis to cover the more intricate scenario in which agents cannot wait and see. That scenario accommodates two stages and stepwise decisions. The …rst stage, referred to as here and now, features investment in catch capacities when future needs are uncertain. The second stage deals with contingent use of sunk investments. This paper adds to [22][2] by allowing two stages, randomness in endowments, and variation in objectives, technologies or skills across agents. For illustration, Section 4 o¤ers an example, and Section 5 concludes.

2. A Stochastic Harvesting Game

There is set I of agents, construed as "…shermen" (or …shing nations). These are all uncertain about which "state of the world" $\omega \in \Xi$ will happen next. They agree however, on the same probability distribution p over Ξ. Agent $i \in I$ owns a quota (a contingent endowment) $Q_{si}(\omega)$ of marine species $s \in S$ in state ω.

This section deals with a simpli…ed setting in which every agent waits to see what contingent activity he should undertake. Speci…cally, when (and only after) state ω is revealed, agent i undertakes …shing e¤ort $e_{sfi}(\omega)$ directed at species s with (gear or) ‡eet type $f \in F$. Since my chief concerns are here with modelling and

[1] Game theoretical studies of …sheries have mainly addressed problems concerning management of transboundary and/or straddling …sh stocks (living within Exclusive Economic Zone of several states and the adjacent high seas), [13], [14], [15], [18], [19]. The focus of the present study is more general for several reasons: First, the cooperative harvesting game …ts all those situations (both intra-territorial and transboundary) where two or more parties bene…t from shared use of random resources. Second, it allows variation in objectives, endowments and technologies/skills across parties. Third, it includes the insurance aspect from aggregated use of random resources. Forth, it allows cooperation across both time and contingencies.

[2] Later studies includes e.g. van Gellekom et al [11] and Samet and Zemel [24].

computations, and not with mathematical niceties, I do not hesitate in assuming that all sets I, Ξ, S, F are fixed and finite.

Bycatch is not regarded a problem. Further, I assume that all species are schooling whence easy to find. So, stock effects on harvesting costs can be ignored to good approximation. Reflecting this, let $\kappa_{sfi}(\omega)$ denote the catchability agent i enjoys when harvesting species s with fleet f in state ω.[3] The state dependent price (or market revenue) $r_s(\omega)$ per unit of species s - and the cost $c_{sfi}(\omega)$ per unit fishing effort - are treated as exogenous parameters. To simplify notations let henceforth

$$\pi_{sfi}(\omega) := r_s(\omega)\,\kappa_{sfi}(\omega) - c_{sfi}(\omega)$$

denote agent i's state dependent payoff per unit effort in "fishery" (s,f). Note that by assumption his total payoff

$$\sum_{s,f} \pi_{sfi}(\omega)\, e_{sfi}(\omega)$$

is separately linear in the various efforts $e_{sfi}(\omega), s \in S, f \in F$. In autarchy agent i would face the constraints

$$\sum_{f} \kappa_{sfi}(\omega)\, e_{sfi}(\omega) \le Q_{si}(\omega) \text{ for all } s \text{ and } \omega.$$

Such constraints pretty much mirror the conditions of exclusive economic zone management. Individual restrictions of this sort will most likely lead to some inefficiencies. The latter can be mitigated, at least in part, by cooperation, resource pooling and exchange. Specifically, in state ω coalition $C \subseteq I$ has the amount

$$Q_{sC}(\omega) := \sum_{i \in C} Q_{si}(\omega), \forall s \in S, \omega \in \Xi$$

available of species s. So, its members could then obtain aggregate, state-dependent, optimal value

$$\left.\begin{array}{ll} v_C(\omega) := & \max \sum_{s,f} \sum_{i \in C} \pi_{sfi}(\omega)\, e_{sfi}(\omega) \\ \text{subject to} & \sum_{f \in F, i \in C} \kappa_{sfi}(\omega)\, e_{sfi}(\omega) \le Q_{sC}(\omega) \text{ for all } s, \end{array}\right\} \tag{1}$$

the aim being to distribute potential gains among themselves.

The characteristic function $I \supseteq C \longmapsto v_C(\omega)$ defines a so-called production game [22]. It turns out that its core is empty. In fact, the game is totally balanced [7].

[3] Harvesting skills or catchability is determined by manifold technical factors (gear, vessel type, know how etc.) that may be difficult to quantify. For simplicity, we tacitly assume that all knowledge that affects harvesting skills can be reduced to a single technical coefficient κ_{sfi}.

Moreover, a core imputation can explicitly be displayed. For this, assume henceforth that problem (1) admits a finite value for each $\omega \in \Xi$ when $C = I$. Then the results in [8] yield:

Proposition 1. (Ex post, state-dependent core allocation) Let $\lambda_s(\omega) \geq 0, s \in S$, be a set of Lagrange multipliers associated to problem (1) when $C = I$. In other words, let $\lambda_s(\omega), s \in S$ be an optimal dual solution to the linear program (1) for the instance $C = I$. Then the imputation

$$u_i(\omega) := \sum_s \lambda_s(\omega) Q_{si}(\omega) \quad \forall i \in I$$

belongs to the core of the game having characteristic function $C \longmapsto v_C(\omega)$ as defined in (1). So,

$$\begin{array}{rl} \sum_{i \in I} u_i(\omega) = & v_I(\omega), \text{ and} \\ \sum_{i \in C} u_i(\omega) \geq & v_C(\omega) \text{ for all } C \subset I. \quad \square \end{array}$$

Note that this result depends on property rights being well defined and truthfully reported (or publicly known). Also, there are no transaction costs.[4]

The game just described, happens ex post, after uncertainty has been resolved. There is also a game ex ante, one that comes with expected values. Indeed, with an eye on (1) let now

$$\left.\begin{array}{ll} v_C := & \max \sum_\omega p(\omega) \sum_{s,f} \sum_{i \in C} \pi_{sfi}(\omega)\, e_{sfi}(\omega) \\ \text{subject to} & \sum_{f \in F, i \in C} \kappa_{sfi}(\omega)\, e_{sfi}(\omega) \leq Q_{sC}(\omega) \text{ for all } s,\, \omega \end{array}\right\} \quad (2)$$

denote the maximal expected payoff to coalition C when pooling their quotas. The results in [8] also imply

Proposition 2. (Ex ante, state-independent core allocation) Let $\lambda_s(\omega) \geq 0, s \in S$, be a set of Lagrange multipliers associated to problem (2) when $C = I$. In other words, let $\lambda_s(\omega), s \in S$ be an optimal dual solution to the linear program (2) for the instance $C = I$. Then the imputation

$$u_i := \sum_\omega p(\omega) \sum_s \lambda_s(\omega) Q_{si}(\omega) \quad \forall i \in I \qquad (3)$$

belongs to the core of the game having characteristic function $C \longmapsto v_C$ as defined in (2). So,

$$\begin{array}{rl} \sum_{i \in I} u_i = & v_I, \text{ and} \\ \sum_{i \in C} u_i \geq & v_C \text{ for all } C \subset I. \quad \square \end{array}$$

[4] The only circumstances that might justify absence of transaction costs in fisheries is that in which the agents have great deal of knowledge about each other and are involved in repeat bargaining [20]. Those circumstances can be found in tribal societies and other small communities. In such a world, transaction costs are very low because of a dense social network of interactions.

A closer look at the allocation rule in (3)

$$u_i := E\sum_{s\in S}\lambda_s \cdot Q_{si} = \sum_{s\in S}\{(E\lambda_s)\cdot(EQ_{si}) + cov[\lambda_s, Q_{si}]\} \quad \forall i \in I$$

makes clear that the "cooperative value" of agent i, as seen ex ante, depends on how much he brings in the mean to the coalition and how his contribution co-varies with the aggregate endowment. Agents that bring much of significant quotas precisely when total abundance is scarce, will be well compensated. They offer some insurance and stability to the cooperative enterprise. It must be emphasized though that aggregate risks cannot be diversified away by mutual insurance.

3. Two-Stage Fisheries with Capacity Choice[5]

The preceding analysis is extended next to a more important setting. Specifically, we now let capacity be part of individual choice. The decision $e_i := (e_i^1, e_i^2)$ of agent i has two chief components. These are the first stage choice $e_i^1 := \left[e_{fi}^1\right]$ and the second stage strategy $e_i^2 := \left[e_{sfi}^2(\omega)\right]$, both being vectors. Here e_{fi}^1 accounts for i's investment ex ante in fleet type $f \in F$. That decision is irreversible[6] and made in face of uncertainty about the upcoming state ω. Further, $e_{sfi}^2(\omega)$ reports the total number of round-trips undertaken ex post by fleet f when owned by agent i and aimed species $s \in S$ is state ω.

Choice and constraints are no longer separable across states as in the previous section: Any investment decision at stage 1 is non-anticipatory. As such it must reconcile with all possible realization of ω at the second stage. Coalition C, in coping with this more difficult scenario, faces the overall two-stage program

$$\begin{array}{llll}
v_C := \max & \sum_{\omega\in\Xi} p(\omega)\left[\sum_{s\in S, f\in F}\sum_{i\in C}\pi_{sfi}(\omega)\, e_{sfi}^2(\omega)\right] & - \sum_{f\in F, i\in C} K_{fi}e_{fi}^1 & \\
\text{s.t.} & \sum_{f\in F, i\in C} p(\omega)\,\kappa_{sfi}(\omega)\, e_{sfi}^2(\omega) & \le p(\omega)\, Q_{sC}(\omega)\, \forall s\in S, \omega\in\Xi & \\
 & \sum_{s\in S, i\in C} d_{sfi}(\omega)\, e_{sfi}^2(\omega) - \sum_{i\in C} D_{fi}e_{fi}^1 & \le 0\ \forall f\in F, \omega\in\Xi & \\
\text{and} & e_{fi}^1, e_{sfi}^2(\omega) & \ge 0\ \forall s\in S, f\in F, i\in C, \omega\in\Xi. & (4)
\end{array}$$

Note that fixed cost are deducted from expected revenues, the unit cost of f being K_{fi}. The first restriction in (4) bounds the aggregate catch of species s to

[5] A similar two-stage stochastic production game has been studied in [25]. The analysis adds to previous studies concerning investment and allocation problems in fisheries facing stochastic revenues [3], [9], [10], [26].

[6] See arguments in [1] and [6].

$Q_{sC}(\omega) := \sum_{i \in C} Q_{si}(\omega)$ in state ω.[7] The second restriction limits total time consumption: $d_{sfi}(\omega)$ is the duration of each round-trip in state ω while D_{fi} is the total amount of available time for fleet $f \in F$ when owned by i. As customary, the technology matrix takes a L-shape form

$$A = \begin{bmatrix} A_{11}(\omega) & 0 \\ A_{21}(\omega) & A_{22} \end{bmatrix} = \begin{bmatrix} \kappa_{sfi}(\omega) & 0 \\ d_{sfi}(\omega) & D_{fi} \end{bmatrix},$$

typical in multi-stage instances of stochastic optimization.[8]

Proposition 3. (Two stages core allocations with capacity choice) Let $\lambda_s(\omega)$ and $\lambda_f^{cap}(\omega) \geq 0$, $s \in S, f \in F$ be Lagrange multipliers associated to problem (4) when $C = I$, representing shared use of quotas and capacity, respectively. Optimal fleet composition and size for the joint enterprise is then found where the fixed cost of the last invested vessel equals its expected contribution

$$K_{fi} = \sum_{\omega} p(\omega)\, \lambda_f^{cap}(\omega)\, D_{fi} \quad \forall f \in F, i \in C.$$

That result in an imputation

$$u_i := \sum_{\omega} p(\omega) \sum_{s} \lambda_s(\omega)\, Q_{si}(\omega) \quad \forall i \in I \tag{5}$$

which belongs to the core of the two-stage game having characteristic function $C \longmapsto v_C$ as defined in (4). So,

$$\begin{aligned} \textstyle\sum_{i \in I} u_i &= v_I, \text{ and} \\ \textstyle\sum_{i \in C} u_i &\geq v_C \text{ for all } C \subset I. \quad \square \end{aligned}$$

Note that the sharing rule in (5) does not differ from (3).[9] Implementation is not dependent on a written contract though. It may as well come about in a decentralized, competitive market for fishing quotas.

4. An Example[10]

For simplicity, let there be only one species, one vessel type, two agents, 10 states, and no uncertainty in revenues or costs. The matrix

$$Q = [Q_{i\omega}] = 10 \begin{bmatrix} 85 & 70 & 45 & 18 & 25 & 40 & 50 & 78 & 93 & 80 \\ 23 & 35 & 60 & 95 & 90 & 70 & 65 & 40 & 18 & 20 \end{bmatrix}$$

[7] The motivation for multiplying the first restriction with $p(\omega)$ is to avoid having the dual solution cum probability. Doing so has, of course, no effect on the optimal value v_C.

[8] Problems like (4) are the object of a substantial literature, e.g. [16], [23].

[9] It would however, if agents faced bounds of the sort $K_{fi} \leq \bar{K}_{fi}$.

[10] The numerical examples in this section are solved by using the computer package AMPL. The model file for the cooperative optimization program is given in Appendix.

records the state-dependent quotas. That is, the entry $Q_{i\omega}$ equals the amount available for agent i in state ω. Both agents are embarking on ...shing as a new activity. Then, if operating alone, agent i would be well advised to solve the following stochastic optimization program

$$\begin{array}{lllr} v_i := & \max \sum_{\omega} [p(\omega) \pi_i e_i^2(\omega)] - K_i e_i^1 & & \\ \text{s.t.} & p(\omega) \kappa_i e_i^2(\omega) & \leq \ p(\omega) Q_i(\omega) \quad \forall \omega & (6) \\ & d_i e_i^2(\omega) - D_i e_i^1 & \leq \ 0 \quad \forall \omega & \\ \text{and} & e_i^1, e_i^2(\omega) & \geq \ 0 \quad \forall \omega. & \end{array}$$

Posit a uniform distribution over Ξ; that is, $p(\omega) = 0.1$ for each $\omega \in \Xi$. Let the parameters in (6) assume values

$$[K_i] = 10^4 \begin{bmatrix} 2 & 1 \end{bmatrix}, \quad [\kappa_i] = \begin{bmatrix} 0.5 & 0.3 \end{bmatrix},$$
$$[d_i] = \begin{bmatrix} 7 & 5 \end{bmatrix}, \quad [D_i] = 10 \begin{bmatrix} 20 & 18 \end{bmatrix}, \quad [\pi_i] = 10^3 \begin{bmatrix} 9.5 & 4.2 \end{bmatrix}$$

The optimal numbers of vessel become

$$e_1^1 = 28, \quad e_2^1 = 32$$

with corresponding pro...t contributions (in thousands)

$$v_1 = 1297, \quad v_2 = 1043 \text{ where } \sum_{i=1}^{2} v_i = 2340.$$

If fully informed about each other endowments and skills, the agents might rather consider to join a cooperative optimization program

$$\begin{array}{lll} v_I := & \max \sum_{\omega} \sum_{i} [p(\omega) \pi_i e_i^2(\omega)] - \sum_{i} K_i e_i^1 & \\ \text{s.t.} & \sum_{i} p(\omega) \kappa_i e_i^2(\omega) & \leq \ p(\omega) Q_I(\omega) \quad \forall \omega \\ & \sum_i \{d_i e_i^2(\omega) - D_i e_i^1\} & \leq \ 0 \quad \forall \omega \\ \text{and} & e_i^1, e_i^2(\omega) & \geq \ 0 \quad \forall i, \omega. \end{array}$$

Here the aggregate state-dependent quota

$$Q_I = [Q_{I\omega}] = 10 \begin{bmatrix} 108 & 105 & 105 & 113 & 115 & 110 & 115 & 118 & 111 & 100 \end{bmatrix}$$

at the second stage. Cooperation increases the total number of vessels from 60 to 86 and generates considerable economic gains:

$$11944 = v_I > \sum_{i}^{2} v_i = 2340.$$

Using the allocation rule in (5) we get the following pro…t allocation

$$[u_i] = \left[\sum_{\omega} p(\omega)\, \lambda(\omega)\, Q_{si}(\omega) \right] = [7682, 4262], \quad \sum_{i}^{2} [u_i] = 11944 = v_I$$

for the two agents and thereby forming of the coalition will take place.

5. Concluding Remarks

While privatizing …sh stocks may solve the problem of "free riding" in …sheries, the appropriators are still left with a coordination problem: The initial allocation of property rights is not likely to be e¢cient. And even if it was, that allocation would probably not last long in …sheries constantly exposed to changes.

We have shown how such parties may better themselves by applying a sharing rule that complies with the core solution concept. That rule invokes tractable optimization programs that allow the agents to cooperate across both time and contingencies. Their dual solutions produce endogenous, contingent market prices that equalibrate competitive markets. Those prices inform about individual contributions for every possible state. As such, they de…ne a long-term contract that provides all potential contributors with su¢cient incentives to participate.

The above results …t observations from many small-scale communities. Sustainability is often secured there through successful sharing of …shing grounds, food, services and skills [4], [5], [12], [17], [21]. The same branch of literature also documents how communal use of property rights depend on complex institutional structures and knowledge systems adapted to the environment over long time. Similar insights have still not reached the international …shery community where property rights tend to be exclusive. This shortcoming might be explained by the fact that institutionalized regimes of the oceans have only been in vigor for few decades. The appropriate institutional framework has not fully evolved yet. It seems important to identify institutional requirements that might facilitate implementing core allocations in …sheries.

6. Appendix

The model …le:

set S; # species
set F; # ‡eets
set I; # agents
set Ξ; # states
param prob {Ξ}$>$=0,$<$=1; # probabilities
param π $\{S, F, I, \Xi\}$; # pro…t per round-trip made by agent i when harvesting

species s with ‡eet f in state ω
param κ $\{S, F, I, \Xi\}$; # catch per round-trip made by agent i when harvesting species s with ‡eet f in state ω
param K $\{F, I\}$; # …xed cost per vessel of type f owned by agent i
param Q $\{S, I, \Xi\}$; # i's quota of species s in state ω
param d $\{S, F, I, \Xi\}$; # the duration of each round-trip made by agent i when harvesting species s with ‡eet f in state ω
param D $\{F, I\}$; # total amount of available time for ‡eet f owned by agent i
var $e1$ $\{F, I\}$ $>$=0; # number of vessels invested in ‡eet type f by agent i
var $e2$ $\{S, F, I, \Xi\}$ $>$=0; # number of round-trips undertaken by agent i when harvesting species s with ‡eet f in state ω

maximize pro…t: sum {s in S, f in F, i in I, ω in Ξ} (prob[ω]*$\pi[s, f, i, \omega]$ *$e2[s, f, i, \omega]$)-sum {f in F, i in I} $K[f, i]$*$e1[f, i]$;

subject to pooled_quotas {s in S, ω in Ξ}: sum {f in F, i in I} prob[ω] *$\kappa[s, f, i, \omega]$*$e2[s, f, i, \omega]$ $<$=sum {i in I} prob[ω]*$Q[s, i, \omega]$;

subject to pooled_vessels {f in F, ω in Ξ}: sum {s in S, i in I} $d[s, f, i, \omega]$ *$e2[s, f, i, \omega]$-sum {i in I} $D[f, i]$*$e1[f, i]$$<$=0;

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